Innovation in The Commons

This essay is a survey of key new tools and technologies which share, at least partially, these attributes: 1) they have relatively low barriers of entry, either because they are simple enough, or they can be put together cheaply enough from a combination of complex but affordable and widespread new technologies that have become available in the last few decades; 2) they have the potential to cause "disruption", i.e. they hold the potential to introduce significant changes to the architecture of communities and societies globally, or to the natural world; 3) they have a high potential for causing large scale externalities, i.e. for damaging the commons; 4) they are being developed at faster pace than informed policy discussions, let alone public engagement and policy formulation. Most of the new technologies that are reshaping the world today are the result of publicly funded research which provided the key ideas and initial tools. The barriers to entry are mainly of commercial nature, and regarded here as relatively low or breakable, while high barriers are considered typically those of "blue sky research", those that only a long term public effort can overcome. The goal is to argue for public education and information as one of the means to avoid unnecessary costs and "tragedies of the commons", helping initiate proactive and dynamically adaptive policy actions. The thesis is that in the face of the new technologies we are developing today, the best way forward is to enhance the design of precautionary policies ex-ante rather than be forced to ex-post palliative actions. Since the commons at higher risk today are global commons, there are no easy paths towards solutions but there is a good case for bottom-up approaches. After all, the world wide web is a new global commons with the potential to enhance participation and get past narrow top-down bureaucratic structures. Science and technology should certainly provide the necessary information through data acquisition, monitoring, surveillance, and testing.

The statement "this time is different" is almost always used in the mood of a certain moment or fashion at a given time and place, only to subsequently be proven wrong. Typically, when this is the feeling about market valuations and stock markets, it soon turns out that not much was different, and a no-nonsense economic analysis would have approximately shown how unfounded the enthusiastic expectations were. Today, the power of our technology does make the case that indeed "this time is different": we may solve the economic problem or end life on the planet; short of that we may reduce the habitable areas of the planet dramatically; we may evolve towards several human species once again but this time custom-made ones; or we may create an "unnatural" world with completely new species of plants, animals, and materials. What is new is not that new technologies bring the capacity for abrupt changes, for "making things different". There are discreet changes through history which nobody voted for, but everybody shared in the consequences of; "disruptive innovations" underpin our history. Presumably the wheel was one such tool that made everything different, and so where techniques for making bronze and iron tools, gun powder, instruments of navigation, the steam and the internal combustion engine, electricity generation and networks, telegraph and communication, and more recently the creation of new hybrid species of plants and animals, using Mendelian genetics, underpinning the first modern agricultural revolution in mid 20th century. Arguably, all of these and many more technology innovations provide tools to use the laws or "the forces" of nature to create an output chosen or modulated to human use. Throughout history "disruptive innovations" were able to dramatically change society but not the way nature works, and ultimately, the effects on nature were gradual. Since the adoption of agriculture humans have been driving the extinction of other animal and plant species. And since the industrial revolution we have been changing the global climate, a process

which could potentially recalibrate human societies. Until the onset of chemical and radioactive pollution, technologies and their consequences were commensurate with the human scale, enhanced by technology, and laid within the grasp of human intuition. This is true even about the ecological consequences of big water dams, erosion of agricultural land. Since the fission of the atom, the release of chemical entities capable of driving fast evolutionary adaptations, and the release of gases into the atmosphere capable of changing the global climate this is no longer true. These consequences clearly escaped intuitive grasp, because of the molecular nature of the active entities, compounded by the scale of the amount released. Arguably the most disruptive innovation has been the technology to release nuclear energy. Humans have for the first time developed the tool to eliminate all life in the planet and, with enough focus devoted to it, even change the orbit of the planet a tiny bit. Climate change could redefine what we have known as habitable environments and drive evolution to completely new plant and animal species, depending on the time constant of the process (the time available). Many new technologies today have the intrinsic potential for causing abrupt large-scale changes to societies and nature globally. Artificial Intelligence and automation could change societies to the same degree the modern industrial revolution did, but the upside can hypothetically be of much higher benefit. The same is true for information and data management, new agricultural chemistry and technology, new materials, nanotechnology, and energy sources and storage. There are at least two types of tools which go much farther, systems biology and genetic engineering, and the reason is that they can literally rewire nature. Using "natural entities" these tools can create new species of plants and animals, that is new "unnatural entities" which could interact and evolve in ways hard to predict and impossible to control. These changes would transcend human intuition and scale of action capacity for correction of unwanted outcomes.

We have no lack of people who fervently believe in "disruptive innovation" and technical fixes for all problems of human societies face today, from scarcity of resources to the natural boundaries upon human freedoms and desires. The community of "technology idealists" is naturally driven by the strong believers for whom "impact" and "change" are by default goods in themselves. They also staff the news and public relation outlets, so that the message is always upbeat, the impact always positive, industrialization, financialization, commercialization always positive in themselves. Mostly unconsciously, they reinforce the narrative in support of the privatization of knowledge in the current regulatory fashion. Technologies which cause "disruptions" well ahead of the formulation of basic norms may very well be most welcome within the neoliberal free markets ideology that has been, deliberately or unconsciously, shaping government policies since the 1980s. If regulation and government involvement can result in no good, and there are no clear mechanisms for bottom-up public engagement, it means we choose to deal with consequences rather to design precautionary policies. The consequences of "the working out of things" however can be costly and irreparable, just at a time when we really do not need to cause damage to obtain affluence. The truth is, the science and technology available today have put us well past the history of humankind until this day: the economic problem, that is the struggle to create enough surplus per individual human being, is potentially solved, except that is for everything that lies outside technology: "the working out of things" by social (political, institutional) mechanisms. The current sophistication of available technology could enable us to create such a large enough and clean enough surplus per individual on the planet, that many patterns of behavior across societies would change. For example, choices regarding use of free time, family size, types and duration of different types of work, and education, could all change dramatically if it were not for "the working of things" built into old institutional and political structures and boundaries. Moreover, the potential for a downside built into our politics is uniquely global for almost any new technology. The opioid crisis enabled by

synthetic chemistry and modulated regulation in the US, and the global pandemic of misinformation through social media are just to examples that make the news, but this is what normally happens with new technologies and no constraints, and there should be no surprise about this. The creation of new biological strains and species, if they are loosely used and released, could enter a new "working out of things" leading to outcomes nobody will choose nor control, but all will pay for one way or another. This is already happening with the consequences of organic chemistry in the hands of oligopolies who modulate regulation to their financial advantage. Antibiotic resistance has been boosted among microbial communities in contact with human societies due to the selective pressure exerted by the chemistry that is released on the environment. Technologies will be used for good or bad according to how power is distributed in societies, the level of information and participation of the public, and the mechanisms in place for correction (checks and balances). New tools will invariably lead to potentially damaging uses.

There is plenty of enthusiasm in technology utopia, with none of the precautionary notes history would counsel. A quick review of the some of the main technology news reports shows this momentum-building attitude towards the privatization and commercialization of science. Even universities have teams publishing news releases and doing public relations. The best-known publications include the following:

The *WIRED* magazine aims to report on new technologies that can impact "society", meaning that can have a commercial impact, or that at least are fancy to report and talk about, and build social media-based chats about (e.g. "Seeking eternal life through liquid nitrogen"). The mood is upbeat and fun, focusing on the upside of each novelty in abstract terms, while leaving out the nuances of how things may work out in the structures of society, let alone in the complexity of unmanaged Nature.

MIT Technology Review reports on technology news and innovation to enable readers "to see, explore, and understand new technologies and their impact", believing that "technology is a powerful force for good" in humanity, period. The publication follows policy news across technology as well, but does not create a forum for engagement and discussion.

GenomeWeb is an internet news organization dedicated to scientific, technical, and commercial novelties underpinned by high-throughput genome sequencing. The publication provides a wide range view of the biotech markets in this sector, focusing on the commercialization not on the potential por downside risks nor on the need for precautionary policy. For instance, it develops a story about the US NIH plan to fund a project to develop "a genome editing toolkit containing the resulting knowledge, methods, and tools that will be shared with the scientific community", but it never discusses potential risks to the commons from these tools.

Science and Nature are the two leading scientific publications in the world. The premise is that the articles and news featured in these journals are of general public interest, due to their scientific novelty and potential for impact in technology.

Fair enough, these accurate filtered reports are an essential contribution, and all of us scientists love research, results, novelty, the uncovering of new potentials. It follows common sense that since these publications implicitly aim to leverage the development of technology and the commercial success of the applications of science coming out of national research budgets, they leave for another day any preoccupation with complicated long-term externalities. However, they become an expression of the one-sided narrative favoring the privatization of knowledge driven by incentives of financialization and

monopolization. “Marketization” has embedded the narratives scientists use today to succeed in being funded, with claims about possible beneficial impacts of the proposed research. Fart-fetched and hypothetical claims include benefits in carbon sequestration, global climate change, antibiotic resistance, human health: a banalization of the actual research questions, a pseudo marketing of the huge positive impact the proposed research may ultimately have for society and the planet. It is as if the marketing “forces” of free market societies in this times of neoliberal ideological preeminence have already transformed the basic research enterprise through the desire to emulate success, in markets terms, by most scientists. A meme got on the loose. There appears to be at least the underlying need to project those forms of representation, most often not consciously.

Research by the economist Mariana Mazzucato[1] has conclusively showed that “the entrepreneurial state” has often identified key challenges in science and technology, and through “blue sky” research programs as well as focused projects brought about most of the innovative, transformative technologies underpinning societies and economies today. However, an opposite dynamic was created throughout the last decades as well, a reflection from the market success of transformative technologies upon the scientific community. The logic of focused efforts in transformative technologies which achieved success creating or leveraging new markets is reflected back upon all public relations and funding requests done in science; with this logic the narrative of most research goals is copied over, whether explicitly or as the coherent thread holding the narrative together. As a result, the corporate logic modulates at least, or directs, at worse, today’s funding for science. Thus, the “Marketization” mentioned above is in big part survival strategy by scientists. There is however, one body of publication consistently calling for policy discussions, precautionary norms and measures, public engagement, and pointing out the shortcomings in current information architectures: The National Academies of the US. Do we see a wide public dissemination of their analysis and recommendations as the basis for a public discussion of key issues in science and technology?

What are a few technologies which appear, today, to have the highest potential for “disruptive innovation” to transform societies and cause a series of “tragedy of the commons”[2-6]?

Genetically modified organisms or GMOs and GM crops

Genetically modified organisms are those in which the original genome has been changed through modifications in their DNA sequence or net additions to their natural DNA sequence. A change in the natural sequence could change a trait or cure a disease. An addition in the DNA sequence could confer entirely new, “unnatural traits” such as resistance to synthetic chemical entities or the creation of a new physiological product, for instance incorporating a gene expressing a new protein or directing the synthesis of a vitamin into a crop. The first genetically modified bacteria in the laboratory were made in the 1970s and the first plant in 1982. The tools were called “DNA recombination” since the new sequence to be inserted was derived from two or more sources, and the technique was called “transformation” since it achieved the alteration of a given cell with the incorporation of a foreign DNA sequence. The tools included a “shotgun” technique literally shooting DNA into target cells, electrical perfusion, and the use of infecting viruses or bacteria as “vectors”, and were extended to plants and animal cells but were not very efficient. Today we are living a true revolution in genetic engineering since a new set of tools called “CRISPR systems” provides simple, effective, and very efficient molecular biology techniques to edit genomes across species of plants and animals in addition to bacteria and archaea. An accurate and educational description of the field and of every term within quotations “” above (and below) can be

found in Wikipedia (https://en.wikipedia.org/). News about the safety of GMO foods, their potential to solve the World's nutrition and food problem for all, and the need to educate the public, can be found in Wired, MIT Technology Review, GenomeWeb, Science, and Nature, dozens of other technical publications, and the occasional newspaper weekend edition or supplement. What cannot be found in Wikipedia or these magazines is any nuanced thought about the complex context for each GMO crop in question and issues other than the "physiological" safety of each specific crop for consumption. This is fair enough as any discussion about unintended consequences of technology becomes as controversial as economic ideology; these discussions if they are serious and genuine belong in political science and policy. Downstream environmental damage is complex enough that it falls to headstrong political activists to discuss it, usually as part of polarizing campaigns to completely abolish the use of GMOs. Proponents of GMOs change the focus using the goal of eliminating hunger and famine to avoid the discussing the complexity of long-term environmental concerns. Thus, the objective, facts-base discussion of pros and cons for each specific case in context never happens. Every use of GMO placed in context is indeed a complex case, since the environmental consequences relate to two factors: the GMO hybrid itself in nature, and the changes in agricultural practices it may bring about either intentionally or unintentionally. Agriculture in the under-developed world poses unique challenges and GMO crops have hard limitations. What ends up happening in the real world is either the full adoption or total prohibition of GMOs, as with US, Brazil, and Argentina using almost only GMO soy beans and corn, or Tanzania preventing any GMO at any scale. Carried by "CRISPR systems" tools, the whole GMO field is now moving much faster than regulation or even policy discussions with concrete actions in sight. When the slow moving political processes permits entry windows or deregulation, the result may turn out to be quite different than intended, as tools and products will change while going through the window already.

The exciting news about Genetically modified organisms include, for example but the list is infinitely longer: drought-resistant white corn; hybrid insect-resistant cow pea; genetically modified banana; designer wheats with low-gluten and high-fiber content; Bt (*Bacillus thuringiensis)* maize which is an insect resistant crop; sweeter strawberries; cacao plant seedlings edited to withstand viral and fungal attacks in research funded by Mars candy company; To sum up and from the Commons of the World Wide Web: Farmland gene editors "want cows without horns, pigs without tails, and business without regulations" and start-ups are "betting biology will be the next great computing platform, DNA will be the code that runs it, and Crispr will be the programming language". Some of the headings prompt an almost automatically positive reaction, who would be at first sight against drought-resistant, insect-resistant, or high-fiber crops? Yet, even the fully benign drought-resistant crops involve much higher costs and lower benefits than advertised by the industry, and the ability of GMOs to solve extreme poverty rather than the bottom line of big farmers and agri-business appears to be contradicted by current evidence. Other concepts immediately make us skeptical about the true value of the new ideas and products. How are we going to be better off with more sugar and candy in our diets, with sweeter fruit, and with innovative new animal forms for automation purposes? Some of the possible bad consequences to ponder, even in the best cases scenarios for safety, jump forth by themselves. We simply need healthier and more nutritious foods which must not compound yet more adverse factors in current endemic health problems like obesity, diabetes, hunger, and low nutritional value diets.

The defense of GMOs in scientific publications is focused on the safety of GMOs as food inputs, the safety to eat GM products directly as foods or as part of a food chain[7]. But they are part of a complex

economic system in which each agricultural practice impacts on soil management and many other species, and every organism is also embedded in a complex fabric of linked factors[7,8]. We go on and on citing scientific opinion about the safety of eating GM foods[7], but we do not seem to consider other consequences of many GM crops to established sustainable agricultural practices or to agricultural practices in general[8], to environmental damage, to the concerns and opinions of the small farmers who would be using them, or to the concern of the public who would consume the production of the big agricultural industry. For instance, GMOs drive mechanized cultivation of monocultures supported by agricultural chemistry and requires the repurchase of seeds yearly. The poor, and no so poor, save seeds and use diversity to hedge against unforeseen weather shocks. The massive use of GMO crops in regions of Brazil, Argentina, and Paraguay goes on very smoothly producing very high yields of grain and export revenues, and without public concern or political wrangling; however, it has consequences for the ecology of these former subtropical forests and for mainstream agricultural practices in areas adjacent to the grain producing region but dedicated to perennial species such as citrus, tea, mate, tapioca. These regions suffer the invasion of weeds with resistance to herbicides, which cannot be fought with the "carpet" chemical applications used in the grain producing plains. Thus, the spread of genes resistant to chemical entities, the abandonment of cycles of different crops, cycles between grains and animal farming, the lower production of cellulose reincorporated to the soil as organic matter, are costly consequences with impact to the commons. It is amusing, and sad, to hear and read "experts" explain what traditionally sound agricultural practices have been all along with new slogans, such as "conservation agriculture"[7]. The slogan is followed by the authoritative explanation that it is "a method that calls for leaving fields unplowed and crop residue in place after a harvest, and, in the offseason, growing cover crops to keep soil nutrients from evaporating or getting washed into streams." Well, soil covers, prevention of erosion, measured plowing, management of weeds and competing species, are old and sound practices that are left aside in the manic excesses leveraged by GMOs either because they enable quicker, easier, and larger returns in the short term, or because the invasion of resistant species generated in GMO-intensive areas derail standard practices. A balanced approached to agriculture would include the use of chemicals with measure and within the context of established practices. The creation and leveraged dissemination of new resistant species destroys any balanced approach. The agricultural industry along technocratic elites that aim to leverage it, would natural propose new chemical to solve the problems cause by the malpractice excesses of older chemicals. How often and seriously are considered the concerns and opinions of the far away poor farmers who they claim are the beneficiaries of big Agri Business initiatives? The public cannot know these nuances, but the distrust placed on new ways to toy with nature imposed in a top-down way is simply an expression of suspecting "Quis custodiet ipsos custodes?", "who shall watch the watchers themselves". Specially when it is the public who pays first for the research, then for the commercial products, and finally to clean up whatever goes wrong. These are just some examples of increased costs imposed to others (than GMOs communities), or externalities which fall upon the private sector involved in other economic activities, and the public as the solutions involve public resources through national agricultural technology extension, monitoring and follow ups. The goal here is not to list and examine the Tragedy of The Commons caused by unrestricted use of GMO technologies, but to point out the immense territory scientists and engineers would have to humbly cover in order to, first, accept the public concerns, and second, engage the public in a process of education of all stakeholders involved, including the scientists "experts" themselves; after all, we all are members of the public. No discussion of this subject reduced to oversimplified arguments

and slogans is a serious and genuine scholarly discussion. It is time to reach out to the engagement of an informed and broad public as a means to help the design of precautionary ex-ante policies.

Agricultural Chemistry

This field is intimately linked with GMOs and with new genetic engineering tools, but some of the uses and abuses can be disentangled. In a nutshell, agricultural chemistry is the industrial synthetic manufacturing of crop fertilizers, plant growth regulators, pesticides, insecticides, fungicides, hormones and chemistry for animal husbandry. Synthetizing fertilizers is a carbon-intensive industrial activity, while the reckless use of chemical fertilizers enables the subsistence of otherwise unviable agricultural practices that neglect conservation. In addition to unintentionally fomenting a higher rate of soil degradation than necessary, they also pollute lakes, streams, and rivers affecting wildlife and human communities. In fact, much of modern agricultural chemistry developed concomitantly with the green revolution that introduced intense use of genetics to agronomy resulting in new hybrid species of plants adapted to a wider geographical and climatic range, high yield grain crops, and new hybrid breeds for husbandry. Together with the incorporation of mechanization, these advances brought huge increases in agricultural production yields worldwide, especially in the developing world. The result was saving hundreds of millions of people from starvation, a diversification of economically viable food products, and economic growth. That was then, and there was a price to pay in deforestation, elimination of natural habitats, and pollution. Arguably the second modern agricultural revolution was brought about by the tools of recombinant DNA and laboratory genetic transformation. These technologies and synthetic chemistry formed a perfect match producing the concomitant development of species resistant to new herbicides and pesticides. Hence started a second wave of chemical pollution with serious environmental consequences, and hold and behold, genetic pollution resulting in the unsuspected marvelous range of weeds resistant to chemical entities. Today we can argue that the main obstacles to starvation are political because new technologies are so numerous and powerful that a better use of what we have would result in a much bigger impact than tinkering ahead in a hurry driven only by commercial goals. Within the current power structures, tinkering ahead may well result in yet higher long-term costs, while the careful use of the technologies we already have, and which are being developed, should help fix the relentless, carefree, creation of externalities. The biggest obstacle to poverty and hunger eradication and to sustainable agricultural practices are likely to be global climate change and human-caused desertification and soil erosion, of which agricultural chemistry is mightily contributing. Climate, soil, the natural world, and the collective knowledge in traditional conservation agriculture, are global commons. Deregulated economic sectors provide entry points to norm-free behavior driven by narrow private expectations of financial returns which result in "Tragedies of the Commons". It is not clear we will collectively benefit from Keynes' prescription rather than his ideal roughly 100 years forth his 1920s prescription[10]: "*We shall once more value ends above means and prefer the good to the useful. But the time for this is not yet. For at least another hundred years we must pretend to ourselves and to everyone that fair is foul and foul is fair; for foul is useful and fair is not. Avarice and usury and precaution must be our gods for a little longer still. For only they can lead us to the tunnel of necessity into daylight*". If we are not out of the tunnel of necessity today, it is not for lack of technology. With agricultural chemistry, foul acquires a literal meaning and a global one. This is because social progress is famously orders of magnitude slower than technical progress. In any case, when the profit motive driving GMOs and agricultural chemistry make incursions into regions with weak governance and high needs they do cause dramatic imbalances.

Gene editing and the new genetic engineering tools

Upbeat news about each new tweak added to the gene editing toolbox and each novel application can be found in Wired, MIT Technology Review, GenomeWeb, Science, and Nature, and dozens of other publications and the occasional newspaper. New tools conceptually bundled under the term "CRISPR systems" provide revolutionary molecular biology techniques to edit genomes of plant and animals in addition to bacteria and archaea. They are affordable, simple, effective, and hypothetically very efficient. Moreover, they sidestep "genetic transformation" of species, which uses sequences from two or more species recombined in the DNA of a single new strain or hybrid. Arguably, by changing only a few letters of a given targeted gene in a single species these tools mimic natural selection and the laborious creation of new hybrids that underpin the "green revolution" of the mid-twenty's century. So goes the argument seeking a deregulated market for the biotech sector based on CRISPR systems. Accurate and educational descriptions of the field and of every term within quotations "" above (and below) can be found in Wikipedia (https://en.wikipedia.org/) as well as in the listed publications. What cannot be found in these publications is any thought about what may happen if, or when, a specific novel gene or novel species in fact, escapes the containment of the intended use and starts a new life into the wild or into society, in plain sight or hidden, just as it is happening with resistant species obtained with older technologies. Or what may happen when unforeseen large-scale changes in the genomes of edited species occur. With this technology, edited genes are hereditary, which is a rather significant novelty of high impact. The whole field is moving much faster than regulation or even public policy discussions with concrete actions in sight.

The exciting news about genetic editing include: edited Jointless tomatoes; healthier foods: healthier oils, higher fiber content; increased flavors; different life-cycle plant times; "CAR T-cell" treatments, a new class of promising therapies that train the body's immune cells to seek and destroy cancers in the blood gene; animal products like meat produced in the lab from cell cultures; animals with novel traits like no sex, no horns, no tails; giant fast-growth fish for farms; male-only lab cows optimize for steak yield per head; hairy sheep (perhaps the first hippie animals, fit for 1960s Woodstock, but no cloud nine idealism here; it's about the profit from more wool per head); personalized pets; personalized babies; personalized body parts to extend our abilities or cure diseases; designed mosquitos; "gene drivers" in insects or animals transmitting endemic diseases to humans or agricultural stocks: a gene driver involves stimulating biased inheritance of particular genes to alter entire populations of organisms. Gene drives may be capable of addressing ecological problems by altering entire populations of wild organisms or causing a large ecological problem by driving to extinction natural species other than the intended target. Only recently some calls for caution were expressed after specific results were publish showing that CRISPR systems may also involve deeper layers of unexpected complexity, as usual in all of science: see GenomeWeb Jul 16, 2018 "CRISPR Genome Editing May Cause More Complex Rearrangements, Deletions Than Previously Thought". Clearly personalized cancer treatment is, and it is happening, a great good; it is unclear that we need "creative" animal anatomic designs; gene drivers and novel genes designed for the release to the environment merit a good deal more of scientific research until enough data is accumulated.

The human genome project (HGP) is one of the best examples of bubbles created by reinforcing interactions between financial markets and overoptimistic scientific expectations. In this case, the scientific assumptions were oversimplified, and the potential commercial impact of sequencing the human genome was consequently overoptimistic. It turned out that the human genome contained a surprisingly small number of genes, a surprisingly large proportion of non-coding DNA, and probably the worst surprise, approximately the same number of genes as mice. The deflation of the market bubble burned money, but the deflation of the scientific expectations bubble caused wasted time and lack of

resources towards understanding the complexity of the non-coding DNA. Today everything seems quite linear and simple with CRISPR systems gene editing, and expectations are sky-high. Have we seen the full course they will run, or "this time is different"? With a more established post Bay-Dole bureaucratic framework for patents and licenses than ever, there is indeed an exponential growth in patents, licenses, and deals, underpinned by a cut-throat litigation jump-start to the privatization of these government funded results (by a large number of nations). Yet it is hard to see why the function of CRISPR tools (enzymes) should be completely isolated of complex interactions just because we have not yet come across them. The US federal government is taking steps that would provide a framework, "NIH Earmarks $7M to Fund Large-Animal Testing Centers for Genome Editing Program", GenomeWeb Jun 12, 2018. In addition to funding science these types of programs provide a praxis for testing results, for controls, and for safety protocols and standards. The private capital raised by CRISPR-based start-ups dwarfs this budget, and what drives their search for applications is the potential market for each result and product. The application of these gene editing tools to plants and animals parallels the previous generation of GMOs but "turbo-charged". There are no apparent limits to the application of these tools. Now virtually any GMO objective is made far more feasible and cheaper, but in addition these tools can aim to create traits that would be practically impossible or very hard before. It is easy to see that, like with any technology, it can be used with a sensical approach, with a shallow financial approach, for good, and for evil. Just with designed insects and plants, the possibility of unwanted ecological effects and near-certainty of spread across political borders would demand careful assessment of each potential application. It is not happening as the momentum for designer mosquitos and fancy plants speeds up. Clearly, the most fundamental question always is "Quis custodiet Ipsos custodes?" ,"Who supervises the custodians". The experience with finance or big pharma and the opioids epidemics shows that public skepticism would be the only prudential attitude towards the new technologies of this era. Very often indeed the answer is that it is the regulated special interests who guide the custodians.

Information Technology: Internet or World Wide Web

A commons is any resource that groups of people (communities, user groups) manage for individual and collective benefit[2-6] through a set of norms. The other attribute of a commons is subtractability of the resource: individual norm-free use subtracts an aliquot of the resource from the community. The internet or World Wide Web is a commons; technology and standards enable a community of users to share data, information, and knowledge. While it may appear that knowledge is non-subtractable, in practice the misuses or dishonest uses of the resource effectively subtract wealth from the commons. The wealth of accurate, objective information available in the internet community is diminish by dishonest practices. Thus, the effective wealth of knowledge is diminished by selfish, norm-free, predatory behavior. The World Wide Web was created by a UK citizen, Sir Tim Berners-Lee, at CERN, an institution funded by the European Union. This is one of the clearest examples of innovation created by publicly funded research at public institutions. The few corporate giants whose business models are underpinned by the internet have *de-facto* privatized this commons and created the conditions for a tragedy of the commons[2-6] as well as a tragedy of the anticommons[9].

The tragedy of the commons has already happened in the world wide web. Indeed, the internet has become an aggressive battleground in several ways. One way is the constant invasion of privacy by hackers stealing emails and private correspondence. Another way is the flooding of false information to elicit behavioral responses, for instance modulating election outcomes. The internet has changed the way we live and the way we work for the better in many ways. We save time by being instantly connected to banks, services, payment centers, health care providers; real communities in which individuals ended at

a distance from each are able to reconnect; virtual communities are formed; people across countries and continents can meet and marry; work groups are routinely connected in real time, facilitating work and increasing efficiency; political action can be started and organized, as the 99 percent and “me too” movements; the economies of under-developed regions of the world have been transformed by the ability of people to communicate and exchange information with simple phones and internet applications. In principle, accurate information can be shared by members of organizations, economic activities, movements, and political parties within societies or across societies. The Brexit campaigns involved a good deal of internet support, and we can argue that the unscientific quality of the information disseminated contributed to the outcome. The internet could be the bases for public engagement in decisions concerning new technologies, before new tragedies of the commons change the natural world and soon the unnatural world as well. The basic question “Quis custodiet Ipsos custodes?”, “who supervises the custodians”, can in part be answered by the World Wide Web unique capacity to support public information, engagement, and direct exercise of choices.

Automation and AI

Artificial Intelligence (AI) can hypothetically free us from the curse of work for subsistence or existence. Bertrand Russell and John Maynard Keynes were contemporaries and very good friends, and Alfred N. Whitehead was Russell’s teacher and co-author. Keynes pondered about a near future in which humans would be delivered from work as toil, roughly within a 100 years from his considerations, and we are roughly at that point in time. So we can use simple concrete thoughts formulated by them, in the context of approximately the same times, to reflect on the potential AI promises. This is the definition of most non-managerial work by Bertrand Russell: “work is moving matter at or near the surface of the Earth relative to other such matter”. That is, toiling, which is not pleasant or generally rewarding per se. J. M. Keynes in “The economic possibilities for our grandchildren” ponders a near future (100 years), in which humankind could be liberated from Russell’s definition of work, of saving the gains from capital for further investment, and of being in general true dedicated capitalists: “We shall once more value ends above means and prefer the good to the useful. But the time for this is not yet. Bertrand Russell’s mentor and co-author Alfred N. Whitehead gives provably the best conceptual framework to describe the painful consequences of the externalities dumped by Keynes’s “avarice” while we are going through the tunnel of necessity and seem ever further from reaching “daylight”. His understanding of human tragedy: "The essence of dramatic tragedy is not unhappiness. It resides in the solemnity of the remorseless working of things." That we focus on unhappiness is just because it makes evident “the futility of escape”. Where Human Freedom, thus choice and morality come in is in setting up the mechanism that will work out outcomes; in society, it is human agency what sets up the incentives and puts in motion a remorseless working of things. Outcomes will generally be consistent with the intentions underpinning the rules and the mechanism created.

The heart of the human conundrum which is “the economic problem” can be solved by AI and the new technologies we have today. Certainly, AI could take care of all forms of work within Russell’s definition, and free up a lot of time from most individuals thus achieving Keynes’s ideal[10] of a shorter working day for “labor”. While all innovations and scientific discoveries should work in synergy, adding “catalytic power” for this transition, what is preventing change is not knowledge. Thus, it makes incomplete sense to argue for the unique value of each iterative improvement in know-how in abstract. How the potential from each technical innovation is released will depend on the structures of powers in each society, and the level of information and participation of the people; that is, the degree of

sophistication of each society. The capture of benefits from economic activity by small powerful groups in detriment of the general level of affluence of the whole society is typical of any age and any state of technology. Eventually, disruptions redefine rules of access and distribution after enough unhappiness made the resistance of status-quos unsustainable.

False Choices

All these new technologies are changing faster than democratic institutions ability to understand them, let alone produce guidelines ahead of commercialization. Let's consider the outcomes of policies (the absence of policy is also policy) which cause widespread unhappiness in the light of Alfred North Whitehead's concept of the essence of tragedy: "The solemnity of the remorseless working of things." An excellent example of the dilemma ahead, should society blindly adapt to the commercial use of technology or should society demand that technology be carefully chosen and tailored to improve chosen ways of life, is the fast-pace introduction of self-driving cars. "Analytics firm Inrix has created a tool that helps cities organize all the rules it expects humans to follow to help train self-driving cars", Wired magazine. That is to say, the public should work, for free, to help corporations make a profit through the introduction of rules that will change how we live. Can we choose the exactly opposite path? How can these technologies be incorporated to cities according to their history, "organically" grown topographies, centuries-old heritages (old European towns) or no heritage (Brasilia), to those communities which feel that the technology would maximize the joy of living in these cities? When new technologies and regulatory framework change basic aspects of how societies are organized, there is a "remorseless working of things" aggregating changes through time and changing the structures of societies. When new technologies open new (conceptual or physical) spaces for human activity ahead of the implementation of norms to rule behavior creating a common-pool resource[3,5,6], the risk is a tragedy of the commons[4]. When top-down management intervenes to fill in the role of "Quis custodiet Ipsos custodes?", "Who supervises the custodians?" in the neoliberal mood of these times, the answer invariably is: the regulated interest that make incursions to the commons, legitimating differential access through the right regulation. Since the ideology that considers the private sector to be the universal solution to all of society's problems and the government to be little else than an obstacle became a prevailing fashion, technocratic management structures have increasingly been put in place top-down and without public accountability. The 1968 article "The tragedy of the commons"[4] appears to be captive to a preconceived political conviction or at least a narrow context, rather than a scientific exploration of the problem. Hardin was a scholar and did not dishonestly falsify the subject to leverage an ideology; rather, he really saw the problem in the terms he set up his article. In his analysis, Hardin[4] artificially constructed the case for top-down government intervention and private enclosure as politics of "privatization or socialism". This is a false choice. Scholarly research has abundantly showed that successful management of common-pool resources are achieved through diverse regimes or architectures to allocate rights[4,5]. As the commons that matter today are global and a tragedy of the commons constitutes a tragedy for humanity and all other living species, the case for a precautionary attitude in the construction of policy frameworks is utterly important. Rather crucial, vital, fundamental. Well, lacking the capacity to form judgements with hindsight notwithstanding the revolutionary wave of disruptive new technologies we are living through (no time-travel in sight yet), the only thing left to try is to form the best possible judgement ex-ante, with foresight. Biology has built robustness using complexity and redundancy, and evolution seems to have generally avoided the selection of streamlined maximum efficiency; that is our territory with fancy engineering. There is in any organism a reservoir of phylogenetically obsolete attributes and vastly more

DNA than used routinely, a sort of mediocracy of final products. Button-up democratic participation may always need to learn to tolerate certain level of mediocracy, both in the process and the final compromised result for each collective goal to be decided. But the inclusion of an informed community of individuals effectively brings complexity to issues upon which decisions need to be made, actions implemented. A large and diverse community will bring multi-valued moral perspectives. Serious participatory democracy with recursive analysis of important issues is the best tool we have to bring clarity and foresight towards the design of policy. This point can be contrasted with a very long and rich list of policies implemented by experts, either at supranational or intermediate tiers of governments. Technocratic solutions explained in simple terms with the promise of solving government caused problems abound. The often-disastrous outcomes are paid for the public who never voted, and often doubted, these heavenly miracle strategies: deregulation and the financial crisis of 2008; the "Washington consensus" economic policies and the default of Argentina in 2001/02; big Pharma and the opioid crisis in the US; the non-existent weapons of mass destruction which justified the second Gulf War by the US and allies; the list can continue to large lengths indeed. Since Regan and Thatcher, the "neoliberal" economic ideology we have witnessed supports the technocratic top-down handling for most problems for which an economic result can be extracted. The result of following these ideologies dogmatically is perhaps best exemplified by Alan Greenspan' genuine and honest contemplation of the 2008 financial crisis: "I made a mistake in presuming that self-interest of organizations, specifically banks, is such that they were best capable of protecting shareholders and equity in the firms ... I discovered a flaw in the model". In his extreme view, he gave the "power of overseers" to the overseen themselves, just to find out they simply set out to derive the assured short-term profit. The neoliberal libertarians who gave the regulated economic structures the power to oversee themselves did not realize these players would turn out to be head-on and dead-end Keynesians: "in the long-term we are all dead" said John Maynard Keynes, so they took care of their interests in the shortest term possible.

The fundamental point is: if Economics is Embedded in Society, it is up to us to decide which set of "remorseless working of things" we choose and towards which "futility of escapes" we go. If Society is Embedded in Economics, or in Markets, then we are already there: the remorseless working of things is in motion, and all attempts to escape are futile. The question today is whether science and technology are embedded in society, and thus contained and appropriately constrained by society, or whether we have reached a point where societies have been embedded already into markets, science, and technology. Once The Commons is changed, e.g. through the extermination of plant and animals species and generation of new ones, the elimination of global homeostasis mechanisms and pollution, or the disappearance of lively European city centers, a slower and cumbersome process of thorough, precautionary policy discussions may seem like a lost golden opportunity.

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